ANNEX I

Methodology for Estimating HFC, PFC, and SF_6 Emissions from Substitution of Ozone Depleting Substances

The EPA uses a detailed vintaging model of ozone depleting substance (ODS)-containing equipment and products to estimate the actual—versus potential—emissions of various ODS substitutes, including HFCs and PFCs. The name of the model refers to the fact that it tracks the use and emissions of various compounds for the annual "vintages" of new equipment that enter service in each end-use. This vintaging model is a "bottom up" model that estimates ODS and ODS substitute use in the United States. It is based on modeled estimates of the quantity of equipment or products sold each year containing these chemicals, and the amount of chemical required to manufacture and/or maintain equipment and products over time. The model estimates emissions from refrigeration and air-conditioning, foams, aerosols, solvents, and fire extinguishing end-use groupings. Emissions from more than 40 different end-uses are estimated by applying annual leak rates and release profiles, which account for the lag in emissions from equipment as they leak over time. By aggregating the data over the different end-uses, the model produces estimates of annual use and emissions of each compound. The methodologies used to estimate consumption and emissions vary depending on the end-use under consideration.

The vintaging model calculates emissions associated with each vintage of equipment on an annual basis. For most products (e.g., refrigerators, air conditioners, fire extinguishers, etc.), emission calculations are split into two categories: emissions during equipment lifetime, which arise from annual leakage and service losses plus emissions from manufacture, and disposal emissions, which occur at the time of discard. For each year, the model tracks which vintages are in use, which are being discarded, how much of each chemical is being recycled, what chemicals are in each vintage, and at what rates these chemicals are emitted.

Some products' lifecycles present slightly different cases that do not fit the criteria necessary for both lifetime and disposal emissions calculations. For example, aerosols, solvents, and foams are not "serviceable" items and will never be "recharged" with an ODS or ODS substitute. To compensate, "non-serviceable" items' emissions are adjusted to reflect either "instantaneous" emissions (for aerosols and solvents) or a "progressive disposal" (for foams) that allows for emissions to extend over a number of years. For example, with aerosols it is assumed that 100 percent of their chemical charge is emitted in the year of production. Hence, the annual disposal emissions for aerosols are set to equal annual aerosol use.[1] Solvent emissions are assumed to be a set percentage of annual use, reflecting instantaneous but incomplete emissions.[2] Foams are slightly more complex, and are given emission profiles depending on the foam type (i.e., open cell or closed cell). The model assumes that a percentage of the foam blowing agent is emitted at manufacture, a small amount is emitted throughout the lifetime of the foam, and some percentage will remain within the foam indefinitely.

For all end-uses, emissions are calculated according to the following steps:

Step 1: Estimate Lifetime Emissions

In order to estimate lifetime emissions, both the amount of chemical leaked during equipment operation and during service recharges are modeled. These are calculated using a baseline value for total ODS in existing equipment in 1985, which is the beginning year of the model.[3] Growth in equipment demand, changes in chemical

[1] This assumption functions independently of when the aerosol is actually used (e.g. whether use occurs during the year it enters the market or in the future). Since there is currently no aerosol recycling, it is valid to consider all of a particular year's production of aerosol propellants as released to the atmosphere.

[2] Generally, most of the solvent used remains in the liquid phase and is not emitted as a gas. Thus, emission is considered "incomplete," and is set as a fraction of the amount of solvent consumed in a year.

[3] While the vintaging model was initialized with data collected in 1985, the assumptions made in 1985 are updated as new information becomes available.

leak and service rates, and substitute phase-ins are used to calculate emissions for any given year. Lifetime emissions in year *y*, for each chemical within each end-use, are calculated as follows:

$$\text{Lifetime Emissions}_{(y)} = \text{Market Penetration}_{(y)} \times \text{Tons Serviced}_{(1985)} \times \text{Yearly Scale Factor} \times \text{Growth Rate}_{(y)}$$

where,

Lifetime Emissions =	the total end-use emissions in year *y* from chemical leak and service recharge.
Market Penetration =	the marketshare (percent) that a particular chemical achieves for that end-use in year *y*.
Tons Serviced $_{(1985)}$ =	the amount of chemical emitted due to leaks and servicing in equipment in 1985.
Yearly Scale Factor =	a percentage that accounts for the difference in leak rates and service rates between a chemical substitute and the original chemical.
Growth Rate =	the demand for the end-use equipment relative to 1985 demand. Growth rates that applied to the original ODS containing equipment are continued for the substitute equipment; however, these rates are modified as new information regarding the growth of the market becomes available.

In general, substitute chemicals that are phased-in at a later date will have a smaller Yearly Scale Factor (and consequently a reduced amount of annual service emissions per unit) than earlier substitutes or the original ODS (i.e., new equipment tends to leak less). This trend is driven by the increased cost of the "newer" substitutes, which drives improvements in product design and servicing practices, and will reduce leakage and service losses. Note that the equation is applied to each chemical, in addition to each year.

Step 2: Estimate Disposal Emissions

The disposal emission equations assume that a certain percentage of the chemical consumed in a particular year will be emitted to the atmosphere when that vintage is discarded. Disposal emissions are thus a function of a chemical manufactured for new equipment in previous years and the proportion of chemical released at disposal, and are calculated using the following equation:

$$\text{Disposal Emissions}_{(y)} = \text{Use of Chemical at Manufacture}_{(1985\text{ to }y)} \times \text{End-Use Disposal}_{(1985\text{ to }y)}$$

where,

Disposal Emissions =	the amount of chemical emitted at the retirement of the equipment.
Use of Chemical at Manufacture =	the amount of chemical used in manufacturing the equipment.
End-Use Disposal =	the percentage of chemical emitted at disposal in year *y* based on the equipment lifetime.

The Use of Chemical at Manufacture and the End-Use Disposal percentage factors represent a timeseries of values. For each year, an End-Use Disposal percentage is associated with the Use of Chemical at Manufacture, based on the lifetime of the equipment. In order to calculate the Disposal Emissions for a particular year, the Use of Chemical at Manufacture values for all the years between 1985 and the current year are used with the corresponding End-Use Disposal Percentage values.

The End-Use Disposal percentage array sets the disposal emissions to occur only when the appropriate vintage year's equipment is actually discarded. The End-Use Disposal percentages for all the "serviceable" goods, such as fire extinguishing, refrigeration, and air-conditioning equipment are always set to 100 percent at the end of the equipment's lifetime. The End-Use Disposal percentage arrays also allow the special cases of "non-serviceable" products such as aerosols, solvents, and foams.[4] Aerosols have a value of 100 percent in the first year, corresponding to the "instantaneous" disposal assumption. Solvents have values around 15 percent for year one and zero for all future years, corresponding to instantaneous and incomplete emission in the same year as production. Foams have End-Use Disposal percentages that fall between zero and 100 percent for year one and also for several following years. This demonstrates "progressive" disposal, where a portion of the chemical is emitted in the blowing process, a portion is emitted during the foam's lifetime, and a portion is emitted at discard. The model

[4] Note that it is simply an artifact of the model that emissions from "non-serviceable" items are attributed to the product's disposal rather than it's lifetime. To calculate annual emissions, both disposal and lifetime emissions for all end-uses are included.

keeps track of which chemical was used in which type of equipment, such that in any given year, the disposal emissions from a given end-use may consist of several ODS or ODS substitutes.

The Use of Chemical at Manufacture value contains the growth adjustments for the increase in chemical demand since the base year (1985) and information on specific chemicals' disposal. Again, this equation is calculated for each chemical within each end-use. It can be written as follows:

$$\text{Use of Chemical at Manufacture}_{(y)} = \text{Growth Rate}_{(y)} \times \text{Tons Manufactured}_{(1985)} \times \text{Market Penetration}_{(y)} \times [1 - (\text{Chemical Disposal Recovery} \times \text{Retirement Vintage}_{(y)})]$$

where,

Use of Chemical at Manufacture =	the amount of chemical used in manufacturing the equipment.
Growth Rate =	the estimated cumulative growth of the industry from 1985 through year *y*.
Tons Manufactured =	the quantity of chemical manufactured in the base year (1985).
Market Penetration =	the manufacturing market share that a chemical has achieved in year *y*.
Chemical Disposal Recovery =	the percentage of chemical that will be recovered from an individual unit at disposal.
Retirement Vintage =	the percent of the equipment being retired from stock in a particular year to the equipment being manufactured as new in that year.

The product of the first three terms represents the growth- and substitution-adjusted demand for a particular chemical in a particular year. The product of the Chemical Disposal Recovery percentage and the Retirement Vintage percentage gauges how much chemical is recovered in a particular year. In essence, it expresses how much chemical can be recovered from an individual unit and how many units will leave the equipment stock.

Step 3: Sum emissions for year *y*

The final step is to sum disposal and lifetime emissions (Steps 1 and 2) across all end uses, by year and by chemical, to provide a profile of ODS and ODS substitute emissions from 1985 through 2030.